Twenty-four hour intraocular pressure measurements and home tonometry

Meier-Gibbons, Frances ; Berlin, Michael S ; Töteberg-Harms, Marc

Abstract: PURPOSE OF REVIEW IOP is the only treatable risk factor contributing to glaucoma and most management and treatment of glaucoma is based on IOP. However, current IOP measurements are limited to office hours and control of glaucoma in many patients would benefit from the ability to monitor IOP diurnally so as not to miss abnormal pressures, which occur outside of office hours Consequently, to improve patient care, the ability to enable accurate and minimally disruptive diurnal IOP monitoring would improve caring for these patients. RECENT FINDINGS The studies we selected for this review can be divided into three categories: self-/home-tonometry, continuous invasive intraocular pressure measurements, and continuous noninvasive ocular measurements. SUMMARY The desire to obtain better insight in our patients' true diurnal IOP has led to the development of home-tonometers, in addition to extraocular and intraocular continuous pressure measurement devices. All of the devices have respective advantages and disadvantages, but none to date completely fulfills the goal of providing a true diurnal IOP profile.Video abstracthttp://links.lww.com/COOP/A27.

DOI: https://doi.org/10.1097/ICU.0000000000000460

Twenty-four hour intraocular pressure measurements and home tonometry

Frances Meier-Gibbons[a], *Michael S. Berlin*[b], *and Marc Töteberg-Harms*[c]

Purpose of review
IOP is the only treatable risk factor contributing to glaucoma and most management and treatment of glaucoma is based on IOP. However, current IOP measurements are limited to office hours and control of glaucoma in many patients would benefit from the ability to monitor IOP diurnally so as not to miss abnormal pressures, which occur outside of office hours Consequently, to improve patient care, the ability to enable accurate and minimally disruptive diurnal IOP monitoring would improve caring for these patients.

Recent findings
The studies we selected for this review can be divided into three categories: self-/home-tonometry, continuous invasive intraocular pressure measurements, and continuous noninvasive ocular measurements.

Summary
The desire to obtain better insight in our patients' true diurnal IOP has led to the development of home-tonometers, in addition to extraocular and intraocular continuous pressure measurement devices. All of the devices have respective advantages and disadvantages, but none to date completely fulfills the goal of providing a true diurnal IOP profile.

Video abstract
http://links.lww.com/COOP/A27.

Keywords
diurnal intraocular pressure, glaucoma, home tonometry, intraocular pressure, tonometry, twenty-four hour intraocular pressure

INTRODUCTION

The effects of glaucoma on the eye have fascinated not only doctors, but also artists for centuries. This interest is such a curiosity that even the origin of the name 'glaucoma' is not fully explained and until quite recently, various myths have surrounded the disease. However, for almost two centuries, it has been well known that intraocular pressure (IOP) plays an important role in the onset and progression of the disease. The intraocular pressure was first determined manually by palpation until Albrecht von Graefe designed the first measuring device (which he ultimately never built) in 1860 [1,2]. Only following the discovery of the topical anesthetic cocaine in 1884 was corneal impression tonometry, which became the basis for modern intraocular pressure measuring devices, enabled.

If we observe the speed of developments in modern medicine, it is remarkable to acknowledge that the gold standard today is a device which was invented in 1957 by Hans Goldmann – that is, the applanation tonometer [3,4]. In his first description of the technique, Goldmann mentioned that the thickness and consistency of the cornea play a crucial role in determining the accuracy of the measurements with his device. However, only many years later with the development of much more precise and accurate technologies were Goldmann's admonitions acknowledged [2].

In the 1970s, nonmedical professions were interested in performing intraocular pressure measurements. However, as they were not permitted to use local anesthetics, Bernard Grolman invented the concept and device for noncontact tonometry, which remains widely in use currently, but the accuracy of noncontact tonometry is constrained

[a]Eye Center Rapperswil, Merkurstrasse 50, Rapperswil, Switzerland, [b]Glaucoma Institute of Beverly Hills, University of California Los Angeles, Stein Eye Institute, Los Angeles, California, USA and [c]Department of Ophthalmology, UniversityHospital Zurich, Zurich, Switzerland

Correspondence to Frances Meier-Gibbons, MD, Eye Center Rapperswil, Merkurstrasse 50, 8640 Rapperswil, Switzerland.
E-mail: frances.meier@bluewin.ch

Curr Opin Ophthalmol 2018, 29:111–115
DOI:10.1097/ICU.0000000000000460

KEY POINTS

- Single IOP measurements during office hours are insufficient for a precise determination of the circadian IOP pattern.
- Continuous IOP measuring devices (intra-ocular or extra-ocular) have been under investigation and development for years; however, at present, no accurate and cost-effective measuring device has reached the market.
- Self-tonometry or home-tonometry devices are promising, but some practical aspects of the methodology remain in need of improvement, especially whenever compared with the effectiveness of GAT measurements.

by multiple factors, which influence the resulting measurements [5].

Understanding the influence of corneal properties as they relate to the accuracy of conventional IOP measuring devices, newer instruments such as the Pascal Contour Tonometer, the Corvis ST tonometer, and the Ocular Response Analyzer were developed [6–9]. These are especially useful for measuring IOP in patients with pathological or postsurgical alterations of the cornea. An additional concept Rebound Tonometry, which enables intraocular pressure measurements without anesthesia, and is especially useful for small corneas, in infants, or animals [10,11].

Knowing that even with all of these instruments, however, we currently capture only a snapshot of the diurnal intraocular pressure, future developments are likely to enable us to obtain and analyze full diurnal measurements. From studies dating back many years, we know that continuous measurements can be obtained either invasively or with a device placed on the surfaces of the eye [12]. Invasive techniques are not feasible in practical ophthalmology and the corneal or scleral surface techniques are hindered by the interpretation of interfering factors, for example, blinking artifacts [13]. However, the development of new surface-based instruments with improved signal to noise technologies are in development and will become commonplace soon.

An alternative to full diurnal IOP measurement is the concept of home-tonometry or self-tonometry, which allows the patient to independently measure their intraocular pressure. Such devices as they enable patients to obtain multiple IOP 'snapshots' per day at various times of day increase information, useful to the care of their disease with information, which can be transmitted telephonically directly to their physicians and thereby may also play an important role in discussions related to healthcare costs.

PURPOSE OF THE REVIEW

The gold standard of intraocular pressure measurements has been challenged in recent years by increased knowledge regarding to the influence of corneal biomechanics on the accuracy of the measurements. Newer technologies have been developed, which allow for more accurate measurements, continuous measurements, and self-measurements. With understanding of the importance of capturing diurnal variations and allowing the patient to check their intraocular pressure at home, such devices may also defer some of the growing costs of glaucoma management. The goal of this review is to provide an overview of the recent literature (published in the last 12 months) on home tonometry and 24-h tonometry.

MATERIAL AND METHODS

A literature search was conducted using PubMed on 1 August 2017. Search strings were 'continuous intraocular pressure,', 'self-tonometry,' 'home-tonometry,' 'triggerfish,' and 'intraocular pressure contact lens.' Manuscripts published between 1 August 2016 and 30 July 2017 have been screened. An additional literature search was performed using the reference list of these publications.

The results have been categorized into self/home-tonometry, continuous, invasive intraocular pressure measurements, and continuous, noninvasive ocular measurements. Manuscripts that were not written in English or review articles were excluded.

RESULTS

Self-tonometry/home-tonometry

Many studies have been conducted on home-tonometry/self-tonometry within recent months [14,15▪,16–20]. The advancements in self-tonometer devices seem to positively affect patient satisfaction as shown through a study by Mihailovic *et al.* [14], which found greater patient satisfaction with Icare Home (Icare Finland Oy, Vantaa, Finland) compared with Icare ONE. A study by Mudie *et al.* [15▪] investigated the Icare HOME rebound tonometer. Interestingly, 23% of the participants were not able to correctly perform home-tonometry correctly even after training [15▪]. The study found meaningful agreement between Icare HOME and Goldmann IOP (Haag-Streit AG, Köniz, Switzerland) (96% were within 5 mmHg) [15▪]. In addition, IOP measured with Icare Home showed lower values whenever

compared with Goldmann IOP (1.03 mmHg lower) and a nonoptimal inter-device agreement (intraclass correlation coefficient 0.641) [21]. In contrast, another study found that Icare HOME tonometry measurements tended to overestimate IOP relative to GAT measurements [17]. A study by Sood and Ramanathan [16] suggested that in patients with progressing normal tension glaucoma, IOP spikes during the out-of-office hours, which could be revealed by self-tonometry are often missed whenever relying solely on office measurements.

Continuous, invasive intraocular pressure measurements

Koutsonas *et al.* [22] published the results of the ARGOS study in 2015. In six patients, a ring-shaped telemetric IOP sensor was successfully implanted in the ciliary sulcus after cataract surgery [22]. The telemetric IOP sensor recorded IOP values similar to those of Goldmann applanation tonometry [22]. Newer data on this device was published in German [23]. The patient population from the ARGOS trial received a reading device 5 months after implantation of the intraocular, telemetric IOP sensor in order to self-record their IOP values [23]. The authors concluded that self-tonometry encourages patients to be actively involved in the management of their own illness [23]. However, the authors mentioned the importance of the correct analysis and interpretation of the recorded IOP data by an ophthalmologist [23]. Mariacher *et al.* [24▪] investigated a different approach by implanting an IOP transducer into the suprachoroidal space of rabbits. Using this approach, the device does not disturb the anterior chamber and the device can be implanted without regard to the status of the lens [24▪]. Biocompatibility was found to be adequate with minimal fibrosis adjacent to the implantation site, and with no signs of inflammation, necrosis, or other pathologies [24▪]. Clinical assessment confirmed good agreement of IOP obtained with the suprachoroidal sensor and intracameral pressure measurements [24▪].

Continuous, non-invasive intraocular pressure measurements

The Sensimed Triggerfish is a contact lens sensor that continuously measures change in ocular surface curvature, which is related to a change in IOP. The Triggerfish does not record IOP directly [25]. The results are transmitted wirelessly to a recorder and can then be analyzed [25,26]. Tojo *et al.* [27] compared IOP fluctuation in normal-tension glaucoma versus nonglaucoma eyes using the Sensimed Triggerfish. They found a larger IOP fluctuation in normal-tension glaucoma eyes compared with those in nonglaucoma eyes [27]. Aptel *et al.* [28] evaluated the effect of selective laser trabeculoplasty on 24-h IOP in untreated primary open angle glaucoma. They found an overall reduction in IOP, but no change in the 24-h IOP profile. Shinmei *et al.* [29▪] looked at 24-h IOP profiles in patients with obstructive sleep apnea syndrome. They observed an immediate decrease in IOP during nocturnal sleep in this group of patients [29▪].

CONCLUSION

We divided the studies into three distinct groups: self-tonometry/home-tonometry, continuous, invasive intraocular pressure measurements, and continuous, noninvasive ocular measurements. The majority of the studies are focused on self-tonometry or home-tonometry. Such studies compare the two most commonly used rebound tonometers (Icare ONE and Icare HOME). Regarding continuous measurements, the majority of studies use the Sensimed 'Triggerfish' and only few others use contact lens sensors. Very few current studies were found, which continuously measure IOP with an intraocular device.

Self-tonometry/home-tonometry

The subject of self-tonometry or home-tonometry has been studied extensively during the past year. It would be interesting, particularly from the standpoint of cost-effectiveness, to enable patients to self-monitor their IOP and subsequently report this data or have it transmitted directly electronically to their ophthalmologist.

Applanation tonometry devices are difficult to use for self-tonometry. Therefore, the majority of the published studies concentrated on rebound-tonometry, which is relatively easier to self-perform and does not require topical anesthesia. It seems that the second generation of rebound-tonometers (i.e. the Icare HOME tonometer) has certain advantages over the first generation (i.e. the Icare ONE tonometer.) One study showed exceptionally interesting facts: There was a good correlation for the majority of the participants (73 of 100). IOP measurements with the Icare HOME tonometer were within 5 mm Hg of the GAT measurements. The Icare measurements, however, were consistently lower than the GAT measurements, especially in the lower IOP ranges [30].

It is evident that a single IOP measurement, especially one, which is obtained only during office hours, does not enable an ideal image of circadian

IOP changes. Yet, we acknowledge that even now we do not have adequate evidence that the progression of glaucoma can be slowed down by obtaining additional IOP measurements. Many other additional factors influence the outcome of this disease. However, the psychological factors of self-tonometry should not be neglected. For some patients, self-tonometry might be a viable option to improve adherence to medication; for others, it might be a burden and an avoidable additional psychological stress.

Continuous, invasive intraocular pressure measurements

Regarding continuous, invasive intraocular IOP measurements, a lack of studies is present. Further investigations are necessary to give a sound recommendation.

Continuous, noninvasive ocular measurements

The main problem of noninvasive, extraocular devices used for continuous measurement of IOP is the fact that we are not certain of what they measure. All studies conclude that the changes identified cannot be directly translated into IOP. In consideration of all contact lens sensors used in the last years, only one has been frequently used in studies: the Sensimed Triggerfish (CLS). According to the producer, it automatically captures changes of ocular dimensions continuously throughout 24 h. The data, however, do not give absolute intraocular pressure values, but instead show intraocular dimension changes at the corneoscleral junction. The measurement value is given in an arbitrary unit, not in millimeters of mercury to which an algorithm attempts to interpret this data into an IOP equivalent. Hence, all assumptions that Triggerfish actually measures IOP are imprecise. However, it is interesting to observe that circadian patterns exist and that the Triggerfish is able to capture short-term and long-term fluctuations in ocular dimensions, which may be related to changes in IOP. Until now, there is an insufficient number of studies showing a direct comparison between the Triggerfish and applanation tonometry or true intracameral IOP measured by cannulation. In 2017, a study by Vitish-Sharma *et al*. [31] compared the Triggerfish with the Tono-Pen XL tonometer and found there was only a weak correlation. One interesting aspect might be observed with a continuous measurement: for years, the influence of body position on IOP has been discussed. One recently published study looked at changes measured with a contact lens sensor and found that there was no significant contact lens sensor mean values between the positions (flat versus 30° head up) at night [32]. Further studies are required, given that the possible influence of head position on the progression of glaucoma could lead to scientific rather than theoretical therapeutic measures.

We conclude that the current studies have demonstrated that there is significant value in improving technologies and techniques for continuous noninvasive measurements of IOP. However, at present, there is no recommendable method which measures actual IOP and for which reproducibility and comparability to Goldman IOP has been proven. Further studies related to the capabilities and effectiveness of these devices and the introduction of new devices are necessary and desirable.

Acknowledgements

None.

Financial support and sponsorship

None.

Conflicts of interest

There are no conflicts of interest.

REFERENCES AND RECOMMENDED READING

Papers of particular interest, published within the annual period of review, have been highlighted as:
- ■ of special interest
- ■■ of outstanding interest

1. Draeger J, Kaefer I. A contribution to the history of tonometry. The first impression tonometer (A. v. Graefe, 1862). Klin Monbl Augenheilkd Augenarztl Fortbild 1959; 135:846–852.
2. Stamper RL. A history of intraocular pressure and its measurement. Optom Vis Sci 2011; 88:E16–E28.
3. Goldmann H, Schmidt T. Applanation tonometry. Ophthalmologica 1957; 134:221–242.
4. Moses RA. The Goldmann applanation tonometer. Am J Ophthalmol 1958; 46:865–869.
5. Grolman B. A new tonometer system. Am J Optom Arch Am Acad Optom 1972; 49:646–660.
6. Hon Y, Lam AK. Corneal deformation measurement using Scheimpflug noncontact tonometry. Optom Vis Sci 2013; 90:e1–e8.
7. Hong J, Xu J, Wei A, *et al.* A new tonometer–the Corvis ST tonometer: clinical comparison with noncontact and Goldmann applanation tonometers. Invest Ophthalmol Vis Sci 2013; 54:659–665.
8. Kaufmann C, Bachmann LM, Thiel MA. Comparison of dynamic contour tonometry with goldmann applanation tonometry. Invest Ophthalmol Vis Sci 2004; 45:3118–3121.
9. Medeiros FA, Weinreb RN. Evaluation of the influence of corneal biomechanical properties on intraocular pressure measurements using the ocular response analyzer. J Glaucoma 2006; 15:364–370.
10. Martinez-de-la-Casa JM, Garcia-Feijoo J, Castillo A, *et al.* Reproducibility and clinical evaluation of rebound tonometry. Invest Ophthalmol Vis Sci 2005; 46:4578–4580.
11. Schweier C, Hanson JV, Funk J, *et al.* Repeatability of intraocular pressure measurements with Icare PRO rebound, Tono-Pen AVIA, and Goldmann tonometers in sitting and reclining positions. BMC Ophthalmol 2013; 13:44.
12. Aptel F, Weinreb RN, Chiquet C, *et al.* 24-h monitoring devices and nyctohemeral rhythms of intraocular pressure. Prog Retin Eye Res 2016; 55:108–148.
13. Faschinger C, Mossbock G, Krainz S. Validity and reproducibility of sensor contact lens profiles in comparison to applanation tonometry in healthy eyes. Klin Monbl Augenheilkd 2012; 229:1209–1214.

14. Mihailovic N, Termuhlen J, Alnawaiseh M, *et al.* Ease of handling of first and second generation rebound tonometers. Ophthalmologe 2016; 113: 314–320.
15. ■ Mudie LI, LaBarre S, Varadaraj V, *et al.* The Icare HOME (TA022) study: performance of an intraocular pressure measuring device for self-tonometry by glaucoma patients. Ophthalmology 2016; 123:1675–1684.
This study tested the Icare HOME tonometer in a large population of patients with glaucoma or suspected glaucoma. Agreement of IOP values between ICare HOME and Goldmann were within 5 mmHg in 91.3% of the patients.
16. Sood V, Ramanathan US. Self-monitoring of intraocular pressure outside of normal office hours using rebound tonometry: initial clinical experience in patients with normal tension glaucoma. J Glaucoma 2016; 25:807–811.
17. Takagi D, Sawada A, Yamamoto T. Evaluation of a new rebound self-tonometer, Icare HOME: comparison with Goldmann applanation tonometer. J Glaucoma 2017; 26:613–618.
18. Chen E, Querat L, Akerstedt C. Self-tonometry as a complement in the investigation of glaucoma patients. Acta Ophthalmol 2016; 94:788–792.
19. Dabasia PL, Lawrenson JG, Murdoch IE. Evaluation of a new rebound tonometer for self-measurement of intraocular pressure. Br J Ophthalmol 2016; 100:1139–1143.
20. Querat L, Chen E. Monitoring daily intraocular pressure fluctuations with self-tonometry in healthy subjects. Acta Ophthalmol 2017; 95:525–529.
21. Noguchi A, Nakakura S, Fujio Y, *et al.* A pilot evaluation assessing the ease of use and accuracy of the new self/home-tonometer IcareHOME in healthy young subjects. J Glaucoma 2016; 25:835–841.
22. Koutsonas A, Walter P, Roessler G, *et al.* Implantation of a novel telemetric intraocular pressure sensor in patients with glaucoma (ARGOS study): 1-year results. Invest Ophthalmol Vis Sci 2015; 56:1063–1069.
23. Koutsonas A, Walter P, Plange N. Self-tonometry with a telemetric intraocular pressure sensor in patients with glaucoma. Klin Monbl Augenheilkd 2016; 233:743–748.
24. ■ Mariacher S, Ebner M, Januschowski K, *et al.* Investigation of a novel implantable suprachoroidal pressure transducer for telemetric intraocular pressure monitoring. Exp Eye Res 2016; 151:54–60.
This article reports the proof of concept of a telemetric suprachoroidal IOP transducer. The device was successfully implanted in six eyes of six rabbits. The transducer was well tolerated and showed good agreement to intracameral IOP.
25. Leonardi M, Pitchon EM, Bertsch A, *et al.* Wireless contact lens sensor for intraocular pressure monitoring: assessment on enucleated pig eyes. Acta Ophthalmol 2009; 87:433–437.
26. Leonardi M, Leuenberger P, Bertrand D, *et al.* First steps toward noninvasive intraocular pressure monitoring with a sensing contact lens. Invest Ophthalmol Vis Sci 2004; 45:3113–3117.
27. Tojo N, Abe S, Ishida M, *et al.* The fluctuation of intraocular pressure measured by a contact lens sensor in normal-tension glaucoma patients and nonglaucoma subjects. J Glaucoma 2017; 26:195–200.
28. Aptel F, Musson C, Zhou T, *et al.* 24-Hour intraocular pressure rhythm in patients with untreated primary open angle glaucoma and effects of selective laser trabeculoplasty. J Glaucoma 2017; 26:272–277.
29. ■ Shinmei Y, Nitta T, Saito H, *et al.* Continuous intraocular pressure monitoring during nocturnal sleep in patients with obstructive sleep apnea syndrome. Invest Ophthalmol Vis Sci 2016; 57:2824–2830.
This article investigated IOP changes during nocturnal sleep in patients with obstructive sleep apnea syndrome. The study found an immediate IOP decline with obstructive apnea.
30. Pronin S, Brown L, Megaw R, Tatham AJ, *et al.* Measurement of intraocular pressure by patients with glaucoma. JAMA Ophthalmol 2017; 135:1–7.
31. Vitish-Sharma P, Acheson AG, Stead R, *et al.* Can the SENSIMED Triggerfish(R) lens data be used as an accurate measure of intraocular pressure? Acta Ophthalmol 2017; doi: 10.1111/aos.13456. [Epub ahead of print]
32. Aref AA. What happens to glaucoma patients during sleep? Curr Opin Ophthalmol 2013; 24:162–166.